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MHS Calib. Alg.
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Microwave Humidity Sounder Calibration Algorithm

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Abstract

A calibration algorithm for processing the Microwave Humidity Sounder (MHS) data into the standard NOAA Level 1B data is developed. This algorithm will be implemented for processing the MHS data, starting with the NOAA-N launch in 2004. The NOAA Polar Orbiter Level 1B data are raw data that have been quality controlled and assembled into discrete data sets, to which Earth location and calibration information are appended but not applied.

1. Introduction

The Microwave Humidity Sounder (MHS) is a five channel total-power microwave radiometer. The spectral characteristics of MHS [1-4] are summarized in Table 1.

Table 1. Spectral characteristics of MHS. The θ is the scan angle.

Channel Number[a]	Central Frequency (GHz)	No. of Bands	RF Bandwidth[b] (MHz)	NEΔT (K)	Polarization angle (degree)
16	89.0	1	2800	1.0	90-θ
17	157.0	1	2800	1.0	90-θ
18	183.311±1.00	2	2x500	1.0	θ
19	183.311±3.00	2	2x1000	1.0	θ
20	190.311	1	2200	1.0	90-θ

[a] Channels 16-20 are also referred to as H1, H2, H3, H4, and H5, respectively.

[b] The quoted values for the maximum bandwidths are double-sideband values and represent the maximum permissible bandwidths at the 3-dB points.

MHS is a cross-track scanning system with a scan angle range of ±49.44°with respect to the nadir direction. Once every 8/3 seconds, MHS measures 90 Earth views, four space views, and four internal black body target views. There are four options for the viewing direction of the space view which can be selected by ground command, and one will be selected immediately after launch. Radiances for the Earth views are derived from the measured counts and the calibration coefficients inferred from the internal black body and space view data. Table 2 provides a list of the main MHS instrument components.

MHS has nominal and redundant Platinum Resistance Thermometers (PRTs) built in the instrument. One set each of 5 PRTs and 3 calibration resistors is routed to the telemetry acquisition circuit of the Processor and Interface Electronics A (PIE-A) and PIE-B, respectively. It also has nominal and redundant local oscillators, Side-A and Side-B. One of the sets will be used for nominal and the other is for backup.

Table 2. Main components of MHS instrument.

Instrument Items	Quantity/Identity	Remarks
Nominal black body PRTs	5	PIE-A
Redundant black body PRTs	5	PIE-B
PRT Calibration Channels	3	PIE-A & PIE-B
Nominal local oscillator	4	Side-A
Redundant local oscillators	4	Side-B
Number of earth views	90	
Number of black body view samples	4	
Number of space view samples	4	
Definition of Instrument temperature	H5 LO Temperature (QBS5)	
Backup Instrument temperature	H1 LO Temperature (QBS1)	

2. Computation of PRT Temperatures

The PRT temperatures are derived in a two-step process. First the PRT counts in the MHS data packets are converted to resistance R (in ohms) using three reference resistor values which are in the data packets (in counts). Subsequent conversion of PRT resistance R into PRT temperature is accomplished using a cubic polynomial of the form,

$$T_k = \sum_{j=0}^{3} f_{kj} R_k^j \tag{1}$$

where T_k and R_k represent the temperature and resistance of the PRT k. The coefficients f_{kj} will be provided for each PRT. MHS has five PRTs (per PIE) mounted on the underside of the onboard calibration target (OBCT). Each PRT is sampled once per scan and these PRT counts are output in the science data packet. The PRT count must be converted into resistance R_k which appears in Equation (1). The process of converting the PRT counts into resistance is described next.

2.1 Three PRT Calibration Channels

MHS has three PRT calibration channels which provide data for a linear count-to-resistance conversion that is updated in each scan. These are precision resistors whose values are known to high precision over temperature and life. Their values are chosen to lie at the upper, middle, and lower resistance values expected of the OBCT PRTs throughout mission life. These three resistors are referred to as the PRT Calibration channels 1, 2, and 3 (PRT CALn, where n=1, 2, and 3), respectively. Their values in counts are measured once per scan and are output in the science data packet. The resistance of the PRT CALn is assumed a linear function of the PRT CALn counts,

$$R_{CALn} = \alpha + \beta C_{CALn} \tag{2}$$

where R_{CALn} and C_{CALn} represent the resistance and count of the PRT CALn, (with n=1, 2, and 3) respectively. The α and β are the offset and slope. For each scan, the C_{CALn} values are measured and the R_{CALn} values, which remain constant, are provided for each MHS flight model. Therefore, the α and β can be obtained by a least-square fit from Equation (2). The results are,

$$\alpha = \frac{\left(\sum_{n=1}^{3} R_{CALn}\right)\left(\sum_{n=1}^{3} C_{CALn}^{2}\right) - \left(\sum_{n=1}^{3} C_{CALn}\right)\left(\sum_{n=1}^{3} C_{CALn} R_{CALn}\right)}{3\left(\sum_{n=1}^{3} C_{CALn}^{2}\right) - \left(\sum_{n=1}^{3} C_{CALn}\right)^{2}} \tag{3a}$$

$$\beta = \frac{3\left(\sum_{n=1}^{3} C_{CALn} R_{CALn}\right) - \left(\sum_{n=1}^{3} R_{CALn}\right)\left(\sum_{n=1}^{3} C_{CALn}\right)}{3\left(\sum_{n=1}^{3} C_{CALn}^{2}\right) - \left(\sum_{n=1}^{3} C_{CALn}\right)^{2}} \tag{3b}$$

2.2 Conversion of PRT counts into Resistance

For each scan, these α and β values are computed and then applied to each OBCT PRT to convert the OBCT PRT count C_k into resistance R_k as follows,

$$R_k = \alpha + \beta C_k \tag{4}$$

where R_k and C_k are the resistance and count of the PRT k with k=1-5. The R_k will be used in Equation (1) for calculation of the OBCT PRT temperatures, T_k, values of which are output to the MHS 1B data.

3. Blackbody Temperature

The mean OBCT temperature, T_W, is calculated from the individual PRT temperatures,

$$T_W = \frac{\sum_{k=1}^{m} W_k T_k}{\sum_{k=1}^{m} W_k} + \Delta T_W \tag{5}$$

where m =5 represents the number of OBCT PRTs (as listed in Table 2) and W_k is a weight assigned to each PRT k. The quantity ΔT_W represents a warm load correction factor, which is derived for each channel from the pre-launch test data at three instrument temperatures (low, nominal, and high). The procedure for determining the ΔT_W values has been described elsewhere [5]. The W_k value, which equals 1 (0) if the PRT k is determined good (bad) before or after launch. For the central PRT, $W_k=2$ will be assigned.

Similarly, a cold space temperature correction, ΔT_C, may be required. This is due to the fact that the space view may be contaminated by radiation which originates from the spacecraft and the Earth's limb. Thus the effective cold space temperature is given by

$$T_C = 2.73 + \Delta T_C \tag{6}$$

where 2.73K is the cosmic background brightness temperature and ΔT_C will be determined from pre- or post-launch data analysis. The ΔT_C values of individual channels and each of the possible space viewing directions will be provided for each MHS flight model.

4. MHS Housekeeping Thermistors and Current Monitors

4.1 Standard Thermistors

There are 24 House Keeping (HK) thermistors which monitor the temperatures at various MHS telemetry points, such as amplifiers, and local oscillators. These data, which are primarily for instrument health and safety monitoring, are not used in the radiometric retrieval algorithm of science data. The accuracy of these HK temperatures is less rigorous than that of the PRT temperatures. The 24 HK thermistors use a common set of conversion coefficients. The two-step process of converting counts to resistance and resistance to temperature can be compressed to a single step with negligible errors. This single step process computes the thermistor temperatures directly from the thermistor counts, using a polynomial of the form,

$$T_{th} = \sum_{n=0}^{4} g_n C_{th}^n \tag{7}$$

where T_{th} and C_{th} represent the temperature and count of the thermistors. The C_{th} is also referred to as the 8 bit code from the Thermistor Telemetry. The coefficients g_n, which are valid for -40° C to 60° C (i.e., 243 K to 333 K), will be provided for each MHS flight model.

4.2 Current Monitors

There are six current monitors that measure the current consumption of various power lines in the instrument. The measured output in count C_I is converted to current, I (in Amps) by a linear relationship as follows,

$$I = I_0 + mC_I \qquad \textbf{(8)}$$

where I_0 is the intercept and m denotes the slope. Values of I_0 and m will be provided for each monitor.

4.3. Survival Thermistors

In the MHS analogy telemetry, there are three survival thermistors which monitor the temperatures of the Receiver, Electronics Equipment, and Scan Mechanism. These survival thermistors are powered to provide measurements even when the instrument power is off.

The conversion of the survival thermistor counts into temperatures is accomplished by a polynomial of the form,

$$T_{SUR} = \sum_{m=0}^{5} h_m V^m \qquad \textbf{(9)}$$

where $V = 0.02$xCount represents the measured output in volts. One set of coefficients h_m apples to all three survival thermistors.

5. Calibration Algorithm

The calibration algorithm [5] that converts the Earth scene counts C_S to radiance, $R_{S,}$ is given as follows,

$$R_S = R_W + \left(R_W - R_C\right)\left(\frac{C_S - \overline{C}_W}{\overline{C}_W - \overline{C}_C}\right) + Q \qquad \textbf{(10)}$$

where R_W and R_C are the radiance computed from the OBCT temperature T_W and the effective cold space temperature T_C, respectively, using the Planck function. The C_S is the radiometric count from the Earth scenes. The, $\overline{C_W}$ and $\overline{C_C}$, are the averaged black body and space counts which are defined below. The quantity Q, which represents the nonlinear contribution, is given by,

$$Q = u\left(R_W - R_C\right)^2 \frac{\left(C_S - \overline{C}_W\right)\left(C_S - \overline{C}_C\right)}{\left(\overline{C}_W - \overline{C}_C\right)^2} \tag{11}$$

where u is a free parameter, values of which are determined at three instrument temperatures (low, nominal, and high) from the pre-launch calibration data. After the launch of MHS, the u value at an actual on-orbit instrument temperature will be interpolated from these three pre-launch values.

For each scan, the black body radiometric count C_W represents the mean of the four samples of black body target. Similarly, the space radiometric count C_C represents the mean of the four samples of space viewing. To reduce noise in the calibrations, the C_X (where X=W or C) for each scan line were convoluted over several neighboring scan lines according to a weight function,

$$\overline{C}_x = \frac{\sum_{i=-n}^{n} w_i \, C_x(t_i)}{\sum_{i=-n}^{n} w_i} \tag{12}$$

where t_i (when $i \neq 0$) represents the time of the scan lines just before or after the current scan line and t_0 is the time of the current scan line. One can write $t_i = t_0 + i\Delta t$, where $\Delta t = 8/3$ seconds for MHS. The 2n+1 values are equally distributed about the scan line to be calibrated. Following the NOAA-KLM operational preprocessor software, the value of n=3 is chosen for MHS. A set of triangular weights, 1, 2, 3, 4, 3, 2, and 1 are chosen for the weight factor w_i that appears in Equation (12) for the seven scans at i = -3, -2, -1, 0, 1, 2, and 3, respectively.

For MHS channel 19, the monochromatic assumption breaks down and a band correction with two coefficients has to be applied. These coefficients modify T_W to give an effective temperature T_W'

$$T_W' = b + c\,T_W \tag{13}$$

which is then used in the Planck function to give an accurate radiance. The application of Equation

(13) is not necessary for the space temperature since the errors in the monochromatic assumption are negligible for such low radiance.

6. Calibration Quality Control

Quality control (QC) in the MHS calibration is very important for producing accurate calibration coefficients in the NESDIS operational calibration process. A scan-by-scan QC process can detect bad data which are flagged in the 1B data sets. All of the QC processes that have been built into the NESDIS operational AMSU-B preprocessor are to be included in this algorithm. These and additional QC items are listed as follows,

- Intra-scan test of black body counts C_W : If any two samples differ more than a preset limit of the black body count variation ΔC_W, the $C_W(t_i)$ should be excluded in Equation(12) by setting w_i=0.
- Intra-scan test of the space counts C_C : If any two samples differ more than a preset limit of the space count variation ΔC_C, the $C_C(t_i)$ should be excluded in Equation(12) by setting w_i=0.
- Inter-scan test of PRT temperatures T_k : If a T_k differs by more than 0.2K from its value in the previous (good) scan line, the T_k should be omitted from the average in Equation (5) by setting W_k=0.
- Test of antenna pointing accuracy : If an antenna position reading is out of a preset limit, then an error flag will be set in the 1B data.
- Radio frequency interference (RFI) correction : It was observed that the transmitters on the NOAA-KLM spacecraft can produce serious RFI to the AMSU-B data. A corrective algorithm was developed for correction of the RFI in the AMSU-B. The same algorithm will also be used in the MHS calibration algorithm. Detailed description of the AMSU-B RFI corrective algorithm is online in Appendix M of the NOAA-KLM User's Guide.[1]
- Detection and exclusion of the Lunar contaminated space samples from the calibration: Calculate the angular separation between the Moon and each viewing direction of the four space samples. Reject those samples that are within a pre-defined angular threshold (default = 1.5°). In the worst case, three samples may be rejected in this process (keep the sample that has the largest separation angle if all four samples fall within the pre-defined angular

[1] http://www2.ncdc.noaa.gov/docs/klm/html/m/app-m.htm

threshold). Description of how to calculate the angular separation between the Moon and the space viewing direction was given elsewhere [6]. Store the calculated separation angles.

- Inter-scan test of sudden jump (or drop) of C_W and C_C : Such sudden change in C_W and C_C has been observed in the NOAA-17 AMSU-A data. A corrective algorithm [7] was developed for correction of the effect of such sudden change in the calibration counts on the calibration coefficients.

7. NOAA LEVEL 1B DATA

The NOAA Polar Orbiter Level 1B data are raw data that have been quality controlled and assembled into discrete data sets, to which Earth location and calibration information are appended but not applied. For simplification of application, one can rewrite Equation (10) as,

$$R_S = a_0 + a_1 C_S + a_2 C_S^2 \tag{14}$$

where the calibration coefficients a_i (where i = 0, 1, and 2) can be expressed in terms of R_W, G, $\overline{C_W}$ and $\overline{C_C}$. This is accomplished by rewriting the right-hand side of Equation (10) in powers of C_S and equates the a_i's to the coefficients of same powers of C_S. The results are,

$$a_0 = R_W - \frac{\overline{C}_W}{G} + u\frac{\overline{C}_W\overline{C}_C}{G^2} \tag{15}$$

$$a_1 = \frac{1}{G} - u\frac{\overline{C}_C + \overline{C}_W}{G^2} \tag{16}$$

and

$$a_2 = u\frac{1}{G^2} \tag{17}$$

where G represents the channel gain and is defined as

$$G = \frac{\overline{C}_W - \overline{C}_C}{R_W - R_C} \tag{18}$$

These calibration coefficients will be calculated at each scan line for all channels and appended to the

1B data. With these coefficients, one can simply apply Equation (14) to obtain the scene radiance R_S. Users, who prefer brightness temperature instead of radiance, can make the simple conversion,

$$T_S = B^{-1}(R_S) \tag{19}$$

where $B^{-1}(R_S)$ is the inverse of the Planck function for radiance R_S. The T_S is the converted brightness temperature.

For MHS channel 19, the band correction must be taken into consideration in the inverse process as follows,

$$T_S = \frac{B^{-1}(R_S) - b}{c} \tag{20}$$

8. Conclusion

An algorithm for calibrating the MHS raw data into the standard NOAA Level 1B data is developed. This algorithm will be implemented to process the MHS data, starting with the NOAA-N satellite which will be launched in 2004. The algorithm also performs quality control of the MHS raw data by checking the consistence of the radiometric counts from the space view and OBCT. Calibration coefficients are generated and appended to the MHS 1B data sets.

Reference

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